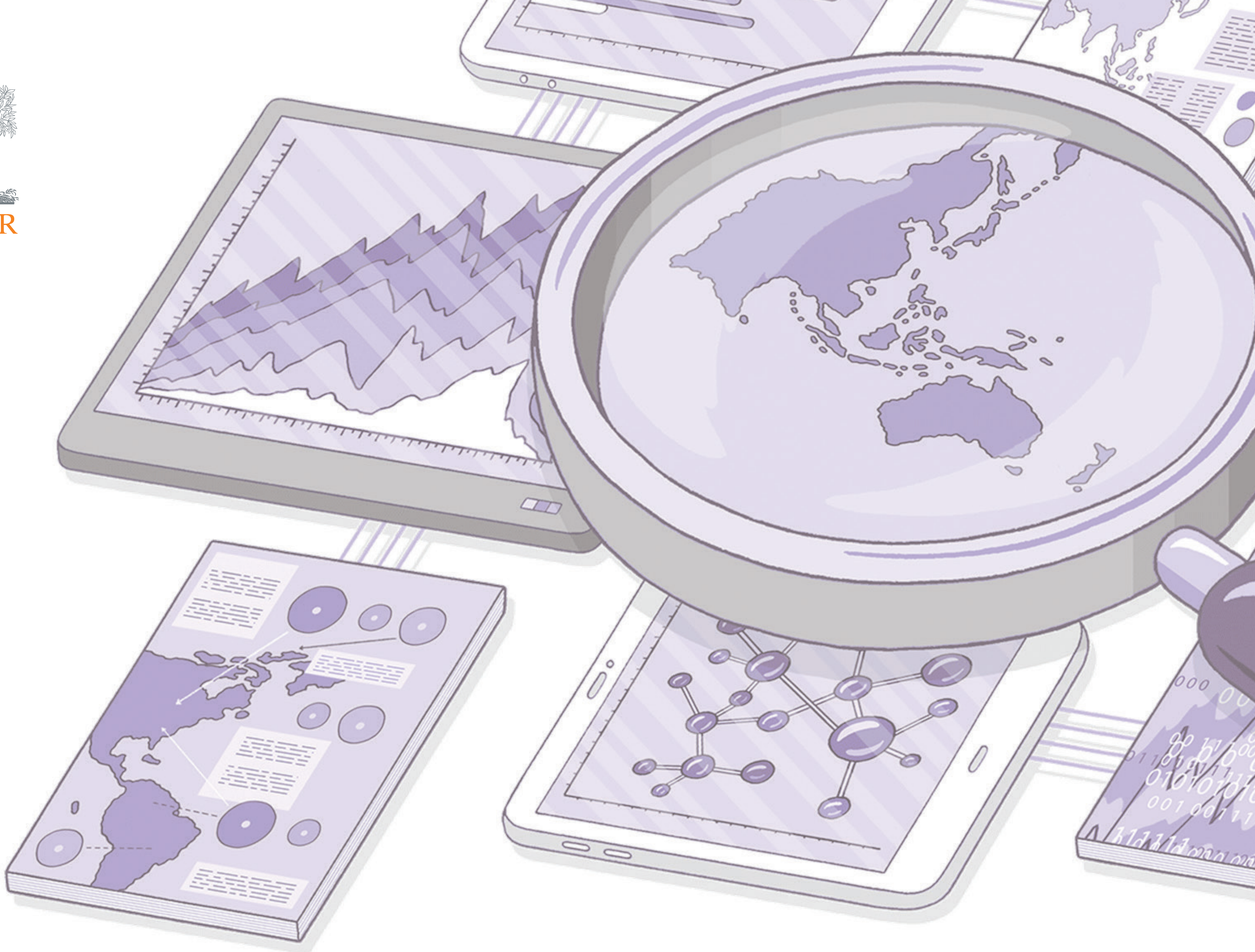


South Korea: A technological powerhouse strengthening its research and innovation footprint

A report in partnership between the National Research Foundation of Korea and Elsevier

Analytical Services

Executive summary

Systematic investment in research and development has moved South Korea from an innovation follower to an innovation leader.

The Republic of Korea—also referred to as South Korea in this report—has been a success story for the world in terms of its transformation from primarily a manufacturing economy to a leading knowledge economy. Currently, with a total for the study period research and development (R&D) expenditure of USD 437,513 million, it ranks 5th in the world. In terms of gross domestic expenditure of R&D (GERD) as percentage of gross domestic product (GDP), at 4.3% it ranks second only to Israel.

The success of South Korea's companies and universities, and its cultural presence globally, has increased interest in collaborating with South Korea and in seeking opportunities to tap into the South Korean market for business, talent, and ideas.

This report from Elsevier in collaboration with the National Research Foundation of Korea (NRF) presents some key indicators around the South Korean research and innovation ecosystem, with comparator countries being the United States, the United Kingdom, Japan, Germany, and China. The main study period of the report is 2015–2019, making the data up to date. With this time window, however, we do not cover how the current COVID-19 pandemic may change R&D funding or prioritize research areas.

Our focus in the report is on academic research, its volume and scholarly impact, as well as on focus topic areas and collaboration networks, both national and international. With three quarters of R&D performed by the corporate sector, the report looks in closer depth at academic–corporate co-publication patterns in terms of scholarly impacts as well as providing novel insights from analyzing patenting activities both in terms of volume and quantity.

A visual summary of some of the key findings is found on the following page. A quantitative summary of some of the key findings of the report is as follows.

South Korea's academic output grew gradually each year from 2015 to 2019, with 81,810 publications in 2015 and 90,292 in 2019, resulting in a compound annual growth rate (CAGR) of 2.0%. South Korea's share of output in the top 1% most cited publications had the second-fastest growth share (CAGR of 7.8%) out of the six comparator countries, indicating very high growth in impactful publications.

Looking at focus areas, South Korea produced relatively more publications than the average global publication shares in 13 fields among 27 subject areas in Elsevier's Scopus database, most notably in Chemical Engineering, Materials Science, and Chemistry.

As is the case for most countries generally, academic–corporate collaborative papers in South Korea had a high citation impact. Samsung was the dominant player in corporate R&D over the study period, and was dominant in terms of academic output from the corporate sector. The academic sector collaborated more widely than the corporate sector, in a sense acting as a bridge within the network. The report provides some detail on these networks.

When we use a composite Patent Asset Index, South Korea ranked fifth worldwide over the study period. The South Korean patent landscape is dominated by the large industry conglomerates—the Chaebols—such as Samsung, LG, and Hyundai. Strong patenting was seen in the field of Electronics, Information and Telecommunication, and academic and government institutes were more competitive in the fields of Pharma and Analyzing Materials, based on the Patent Asset Index and portfolio size.

The report details data and insights on the South Korean research and innovation landscape, which are only highlighted above. It is our hope it will spur further discussion and inspire collaborations.

Key findings

Strong and growing investment in R&D

2015–2019

South Korea had the highest GERD% of GDP (4.3%) among the comparator countries, with a CAGR of 2.7%.

Strong research focus

2015–2019

South Korea's publication share is higher than the global average in Chemical Engineering (+73%), Materials Science (+64%), and Chemistry (+46%).

Strong growth in high-impact publications

2015–2019

Share of output in the top 1% most cited publications had the second-fastest growth (CAGR of 7.8%) out of the six comparator countries.

High impact in international academic–corporate collaboration

2015–2019

South Korea's academic–corporate collaboration FWCI was 1.8, and its international collaboration FWCI was almost twice that at 2.9.

Beneficial collaborator in academic–corporate collaboration in terms of FWCI

2015–2019

Collaborating with South Korea results in a higher FWCI for top GII countries engaging in academic–corporate collaboration.

Academic–corporate collaboration highly concentrated in certain institutes and fields

2015–2019

Samsung contributes the most output and an extensive network connection. Engineering is the most productive area.

Growing in innovation power

2000–2019

South Korea's patent portfolio has been steadily growing, in terms of both quality and quantity.

Strong technology field focus

Patent families active in August 2020

South Korea's current core technology fields are Semiconductors and Electric power, within Electronics.

Preface

Dr. Roe, Jung-Hye

President, National Research Foundation of Korea (NRF)

This report, created in in partnership with Elsevier, is a great opportunity to not only analyze South Korea's recent trends in research outputs and strategic R&D investment but also highlight the strength and growth in South Korea's research and innovation to the global research community and potential partners in research.

South Korea is striving to become a science and technology powerhouse through the creation and maintenance of an innovation ecosystem that promotes both autonomy and responsibility in research. The government-supported initiative is designed to support research institutions and researchers to maximize their potential for research. As detailed in the report, South Korea has achieved significant growth in research output and knowledge transfer over the past few years—in both quality and quantity—with support from such government policies along with strategic R&D investment and a strong contribution from researchers.

NRF also plays a pivotal role in South Korea's journey toward research excellence and innovation in several capacities. NRF, as a national funding agency, intends to set the direction of basic and applied research across all academic disciplines, lead changes in future-oriented research ecosystems, and become a platform and facilitator of interaction among universities, research institutes, and researchers. On the other hand, NRF as a platform for knowledge creation strengthens capacity for innovation, creativity, openness, and collaboration and strives to sustain the healthy research ecosystem.

We hope that this report provides a glimpse of our progress and collective efforts from the government, research communities, and researchers in South Korea over the past several years. We also hope that this report can shed some new light on the current direction of research and innovation in South Korea to research communities around the world and facilitate opportunities for collaboration and knowledge sharing.

Dr. Roe, Jung-Hye

President

National Research Foundation of Korea

Contents

Introduction

South Korea’s rapidly increasing excellence in research and innovation makes the country an attractive partner for collaboration.

From semiconductors, shipyards, and consumer electronics to smart cities with the world’s fastest broadband, in 60 years—through the period known as the Miracle on the Han River—South Korea has moved from being an innovation follower to an innovation leader. The Government of South Korea is supporting sustainable research and development (R&D) investment to create an innovative ecosystem with more autonomy and responsibility for science and technology. It aims to foster fundamental research as well as targeted strategic areas to remain among the world’s leading knowledge economies in the 21st century. South Korea is second only to Israel in terms of gross expenditure on R&D, at 4.3% of GDP, and increasingly its research ecosystem is becoming more strongly connected internationally. With this increasing global research and innovation footprint, universities, industries, and governments all over the world are looking at South Korea, both with respect to strategic collaborations and from a competitiveness perspective. In this report, completed in collaboration with the National Research Foundation of Korea (NRF), we present some basic facts about the South Korean research and innovation system and, given the increasing role of academia in the research and innovation ecosystem, we look in more detail at the publications and patents landscape of South Korea’s institutes and industries.

Over the years, a number of funding programs have been put in place to boost the academic strengths of South Korean research. To highlight just one very important program, BK 21 PLUS (Brain Korea 21 Program for Leading Universities and Students) aims at fostering world-class universities and outstanding scholars by providing funds to higher education institutions. It was initiated by the Ministry of Education, and the NRF leads knowledge production, technological development, and industry collaboration. As a result of this program and others, the research outputs of South Korea increased by 2.5% annually between 2015 and 2019, and universities have tried to increase their research impact, as measured by an indicator of World University Ranking, to become global leading universities. As universities are increasingly paying attention to the quality aspect of research, outputs in the top 1% most cited publications, the top 1% citation percentiles by business expenditure on R&D (BERD), and full-time equivalent (FTE) researchers have shown continuous growth up to 2019. Despite the growing international competition among universities around the world, 7 South Korean universities were ranked in the top 200 by the 2020–2021 QS World University Ranking, by virtue of government support and the quantitative and qualitative growth of research.

To look now in more detail at academic–corporate collaboration, South Korea has been heavily dependent on its industrial conglomerates—known as Chaebols in the Korean language—such as Samsung, LG, Hyundai, SK, and more. Among the research support provided by industry, the Samsung Science & Technology Foundation leads strategic research projects and affects other corporates, as well as attracting attention from research institutes. Since 2013, the Foundation has supported

a huge amount of research funding to foster the development of basic science, materials engineering, and information technology, including pioneering research.

In this report, we also take a closer look at the patenting that is crucial to the innovation and deployment of technologies. In a rapidly changing environment, the competitive advantage of patented assets is very important for research institutes and industries in South Korea, so they can acquire breakthrough technology quickly. We can identify via patents that South Korea is relatively strong in Semiconductors, Electric power, Pharma, and Analyzing materials due to its export-oriented and manufacturing industry-led economic structure.

This report is based upon research activities and patenting up to 2019. Hence, it does not address how the 2020 COVID-19 pandemic has changed the research landscape in the near term in terms of priority setting for funding, nor does it address long-term changes in society, notably on how the acceleration of the digital transformation may change society. However, history provides a lesson, and during the COVID-19 pandemic South Korea has shown significant resilience. It has built its rapid response based on its capabilities as a leading research and innovation nation. Thus, it can be expected that the strengths and potential weaknesses of its research and innovation ecosystem that we analyze in this report will also serve as a good blueprint for how South Korean society will move forward, post the current pandemic.

Methods

Analytical scope

The NRF and Elsevier are delighted to present a novel perspective on South Korea's research landscape, thanks to the multifaceted array of analyses included in this report. We derive new insights from the combination of data on investments, human capital, research outputs and impact, universities' competitiveness, knowledge transfer though academia and industry, patents, and underlying indicators.

Benchmarking

Benchmarking enables us to evaluate the research excellence, academic–corporate collaboration, and patents of South Korea compared to five other countries: China, Japan, Germany, the United States, and the United Kingdom. For academic–corporate collaboration at the country level, we analyze, by subject, the collaboration status of South Korea with other Global Innovation Index countries.

Data sources and methodology

- The United Nations Educational, Scientific, and Cultural Organization (UNESCO)
- The Organisation for Economic Co-operation and Development (OECD)
- Scopus, Elsevier's abstract and citation database of peer-reviewed literature, which covers over 75 million documents from over 25,000 active journals, book series, and conferences by some 5,000 publishers
- PatentSight, which evaluates patents from 100 global intellectual property organizations using a scientifically developed proprietary methodology, the Patent Asset Index™

More information on the data sources and methodologies used in this report can be found in the report's appendices.

Period studied in this report

This report is based on the years 2015–2019 for research investments, human capital, research outputs and impact, and academic–corporate collaboration, and on the years 2000–2019 for patents.

Document types

Publication output and citation-based analyses are employed for all of the document types that are indexed by Scopus.

Research field delineation

Delineation of fields is based on the 27 main subject areas in the All Science Journal Classification (ASJC) used in Scopus.

Keyphrases

For academic–corporate collaboration analysis, we used the Elsevier Fingerprint Engine, which uses text mining and applies a variety of natural language processing techniques to extract distinctive keyphrases from titles, abstracts, and author keywords of the documents in a particular research area.

Time lags between research inputs and outputs

In the input–output model of R&D evaluation, inputs (such as R&D expenditure or human capital) must precede outputs (such as publications or citations). The results of research done based on funding provided in 2015 may only be published several years later. Such lags vary by indicator, country, and subject field. Determining or accounting for the lags in time between research inputs and outputs has not been attempted in this report.

Chapter 1

Expenditure on R&D and research output and impact

1.1 Gross expenditure on research and development in South Korea

For 2015–2019, South Korea has the highest R&D expenditure in terms of GERD per GDP (4.3%) and BERD per GDP (3.4%) among the comparator countries, as well as the highest growth.

Expenditure on research

A key indicator to assess the priorities put into R&D is to look at the research expenditure as a percentage of gross domestic product (GDP). As an indicator of the R&D intensity of a country's economy, both over time and in comparison with other countries, gross domestic expenditure on R&D (GERD) is often presented as a ratio of GERD divided by GDP. Hence, GERD-to-GDP ratios are a useful means for normalizing large differences in countries' aggregate R&D totals that might partially reflect the large differences in the size of countries' overall economies.

GERD is defined as "the total expenditure (current and capital) on R&D carried out by all resident companies, research institutes, university and government laboratories, etc., in a country".[1] Therefore, GERD is constructed by summing the intramural R&D expenditure totals for the four main sectors: business enterprise (BERD), government (GOVRD), higher education (HERD) and private non-profit (PNPRD).

The GERD of South Korea averaged USD 87,503 million per year between 2015 and 2019, ranking 5th in the world.[2] As GERD is a size-dependent indicator, a better way to benchmark research investment is to compare GERD as a percentage of GDP. Between 2015 and 2019, South Korea's average GERD as a percentage of GDP was 4.3%. As we focus on knowledge transfer in this report, it is also relevant to consider BERD as a percentage of GDP, which was 3.4% for South Korea in the same period. In terms of both GERD and BERD expenditures, South Korea was ahead of all comparator countries (Figure 1-1). All comparator countries except the United Kingdom had higher expenditures than the OECD average.

[1] https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

[2] OECD constant prices in May 2020 for China, Germany, Japan, South Korea, United Kingdom, and the United States

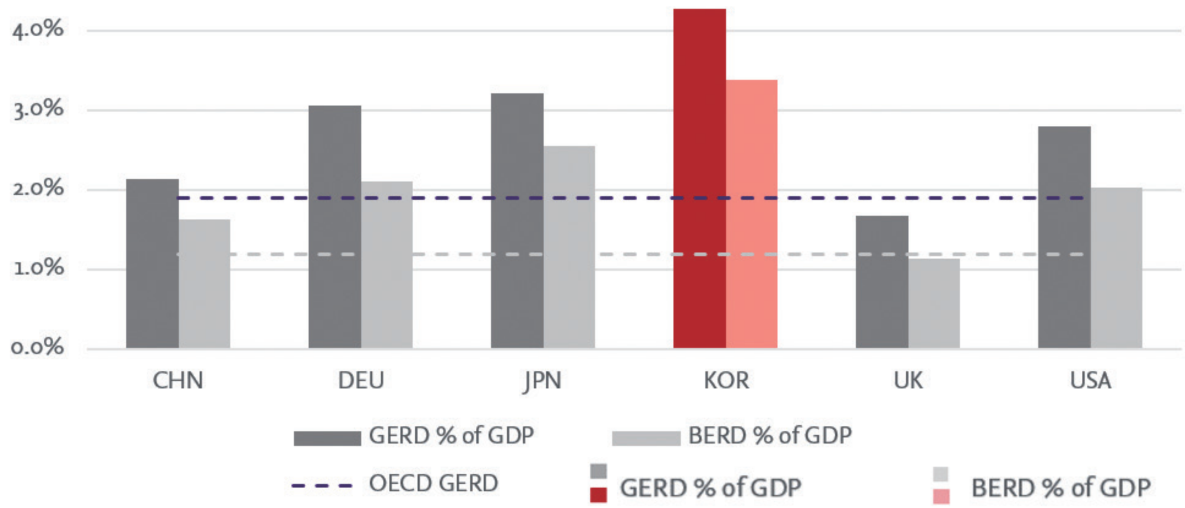


FIGURE 1-1
Gross expenditure in research & development (GERD) as share of gross domestic product (GDP), business enterprise expenditure in R&D (BERD) as share of GDP, 2015–2019
Source: OECD constant prices, May 2020, for China, Germany, Japan, South Korea, the United Kingdom, and the United States

Annual research expenditure by % of GDP and researcher FTE

Gross expenditure in R&D as % of GDP

South Korea invested the highest GERD% of GDP among the comparators in the period 2015–2019, at 4.3%, and it also showed strong growth in expenditure with a compound annual growth rate (CAGR) of 2.7%, which is the highest among the comparator counties. All comparator countries, apart from the United Kingdom, showed spending above the OECD average during the same period, and this spending had a stable trend without apparent change (Figure 1-2, left).

Business expenditure in R&D as % of GDP

South Korea had the highest BERD% of GDP among the comparator countries, at 3.4% between 2015 and 2019, and it was second in the world within the same period of time, with Israel first (4%). South Korea's BERD% of GDP rose gradually from 2015 (3.1%) to 2019 (3.7%), with the highest CAGR (3.4%) among the comparator countries; the comparator countries did not show as much growth as South Korea. Japan had the next highest BERD% of GDP, followed by Germany, the United States, China, and the United Kingdom. The United Kingdom was the only comparator country with spending below the OECD average throughout the years 2015–2019 (Figure 1-2, middle).

Number of FTE researchers

China had the highest number of FTE researchers, with an average of 1.76 million, which is nearly four times the number

of South Korea's FTE researchers, at an average of 0.39 million in the period 2015–2019. However, this is expected in line with the populations of the countries. China also had a high growth rate, with a CAGR of 3.6%, followed by Germany (CAGR of 3.3%) and South Korea (CAGR of 3.2%). Compared to the other countries here, South Korea was lower in terms of researcher numbers, only higher than the United Kingdom. However, South Korea had the highest number of researchers per 1,000 employed, according to OECD data on researchers in the peer group.[3] All the comparator countries had an increasing CAGR in terms of research FTE, though Japan showed the least growth, with a CAGR of 0.4% (Figure 1-2, right).

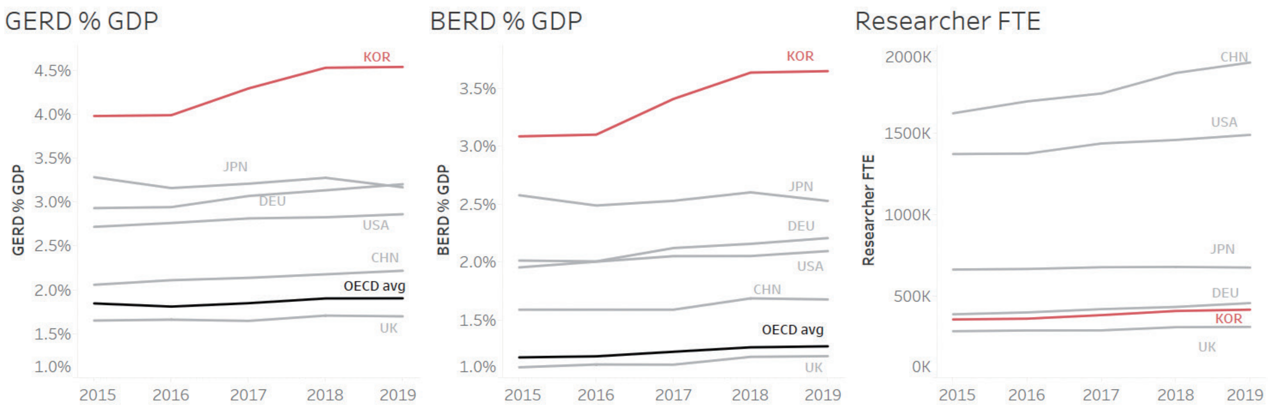


FIGURE 1-2
Annual trend of gross expenditure in research & development (GERD) as share of gross domestic product (GDP) (left), business enterprise expenditure in R&D (BERD) as share of GDP (middle) and full-time equivalent (FTE) researchers (right). Red line represents South Korea, black line represents OECD average, grey line represents other comparators. 2015–2019
Source: OECD constant prices, May 2020, for China, Germany, Japan, South Korea, the United Kingdom, and the United States

[3] https://data.oecd.org/rd/researchers.htm

1.2 Research output and impact

South Korea's share of output in the top 1% most cited publications has the second-fastest growth (CAGR of 7.8%) out of the comparators.

Scholarly output of publications

South Korea's publications grew gradually each year from 2015 to 2019, with 81,810 publications in 2015 and 90,292 in 2019, resulting in a CAGR of 2.0%. In the comparator countries, the United States started from the highest output in 2015, whereas China reached its highest output in 2019, with the highest CAGR for 2015–2019 at 8.6%. The scholarly outputs of the United Kingdom, Germany, and Japan were higher than that of South Korea; however, output is a size-dependent indicator. It is worth noting that the United States, the United Kingdom, and Japan had a decline in output during 2018–2019; Germany was relatively stable (Figure 1-3, left).

Field-Weighted Citation Impact of publications

The impact of South Korea's publications, as measured by the Field-Weighted Citation Impact (FWCI), changed little in the period 2015–2019, from approximately 1.0 to 1.1. This is slightly above the world average. China started from 0.9 in 2015, which is below the world average; however, China has reached the same level as South Korea in recent years. On the other hand, Germany, the United States, and the United Kingdom showed declines in their overall FWCIs from 2015 to 2019, but they all had an overall higher impact than South Korea, China, and Japan (Figure 1-3, middle).

Share of output in the top 1% most cited publications

South Korea's share of output in the top 1% most cited publications had the second-fastest growth rate (CAGR of 7.8%) out of the six comparator countries, indicating a very high growth rate on impactful publications. However, the overall FWCI is stable (Figure 1-3, middle), indicating that the portion of less impactful papers is also increasing. China had the fastest growth in share of the top 1% most cited publications during this period, with a CAGR of 9.0%. Germany, the United Kingdom, and the United States declined in their share of the top 1% most cited publications, but their shares remained higher than that of South Korea. Japan showed an increase in its share of the top 1% most cited publications, but it had the lowest share among the comparators (Figure 1-3, right).

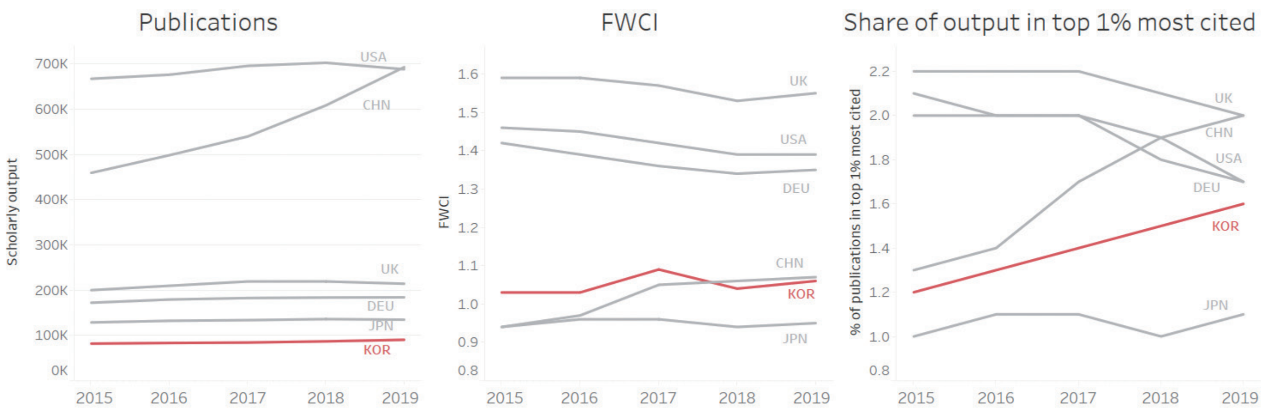


FIGURE 1-3
Trends of publication output (left), Field-Weighted Citation Impact (FWCI) (middle), and share of output in the top 1% most cited publications (right), 2015–2019
Source: SciVal, August 2020

Chapter 2

Research fields and institutes

2.1 Relative Activity Index and subject area impact

South Korea’s publications are relatively more focused toward Chemical Engineering and Materials Science, but its scholarly impact is highest in Chemistry, Medicine, Materials Science, and Environmental Science.

South Korea’s Relative Activity Index in subject categories

In order to understand which areas of research South Korea is active in and its scholarly impact per subject, we illustrate these aspects using two indicators, the Relative Activity Index (RAI) and the FWCI, both of which are standard bibliometric indicators.

The RAI is defined as the share of a country’s publication output in a subject relative to the global share of publications in the same subject. For instance, South Korea had a RAI of 1.73 in Chemical Engineering, meaning that in relative terms its national share of Chemical Engineering publications was 73% higher than the global average share of publications in Chemical Engineering. Hence, we can interpret these data as indicating that South Korea had a relatively higher concentration of publications in Chemical Engineering compared to the global average.

The FWCI is a normalized indicator of citation levels in each subject area, rebased to the corresponding world average level in the same subject area, and can thus be used to analyze South Korea’s relative research impact. For instance, South Korea had an FWCI of 1.2 in Chemistry, meaning that in relative terms its publications in Chemistry have been cited 20% more than the global average for similar publications. Similar publications are those publications in the Scopus database that have the same publication year, publication type, and discipline, as represented by the Scopus ASJC[4] system.

[4] Titles in Scopus are classified under four broad subject clusters (life sciences, physical sciences, health sciences, and social sciences & humanities), which are further divided into 27 major subject areas (the ASJC27) and 300+ minor subject areas. Titles may belong to more than one subject area

In terms of RAI, South Korea had a higher than global share of publications in 13 areas over the study period (Figure 2-1), with a considerably high focus on Chemical Engineering (+73%), Materials Science (+64%), and Chemistry (+46%). The same chart also shows the subjects in which South Korea had a higher impact than the global average. These include, but are not limited to, Chemistry (1.2), Medicine (1.2), Materials Science (1.2), and Environmental Science (1.2).

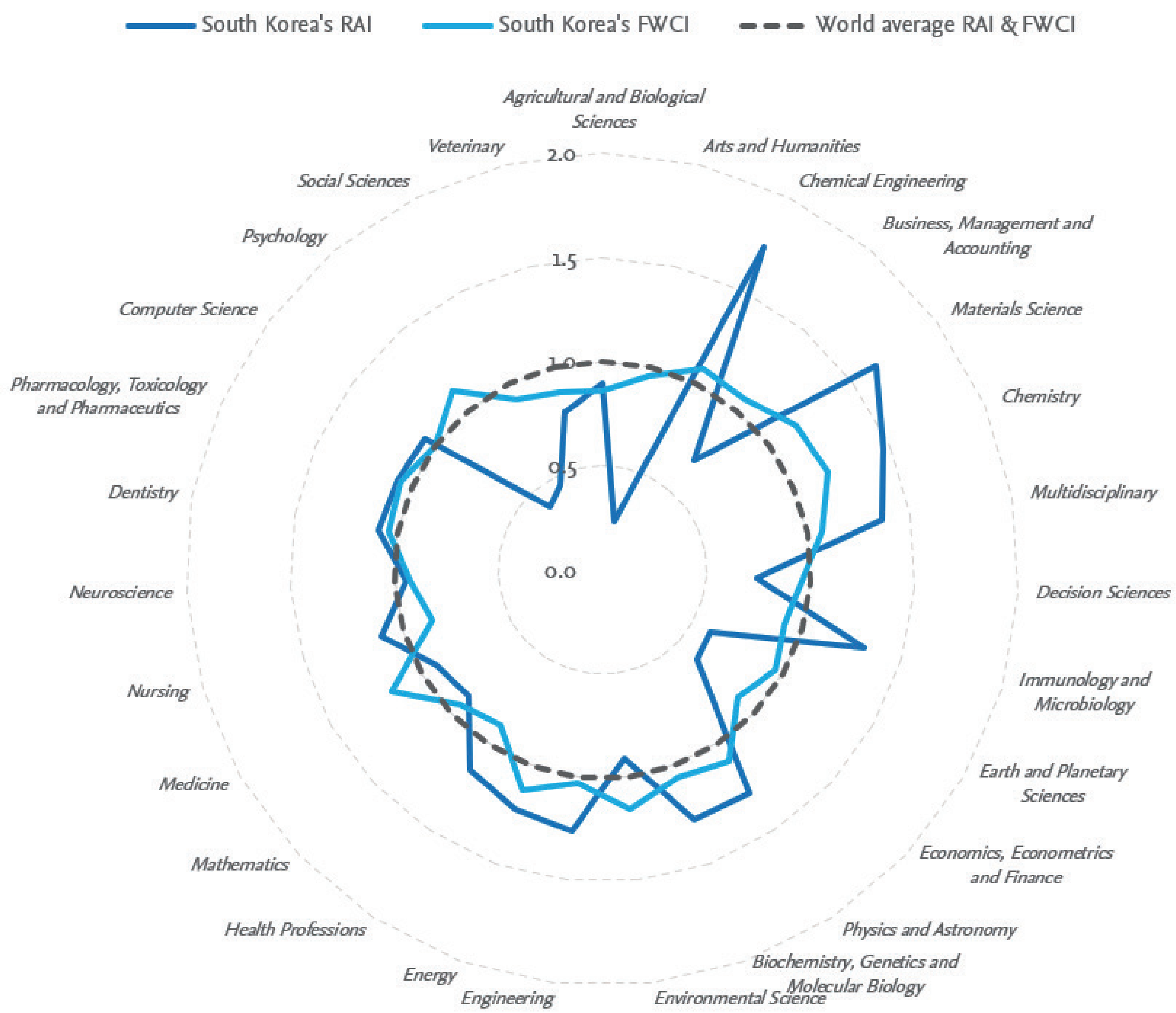


FIGURE 2-1
Relative Activity Index (RAI) and Field-Weighted Citation Index (FWCI) of South Korea's publications belonging to the ASJC274 subject categories, 2015–2019
Source: SciVal, August 2020

2.2 Top institutes by scholarly output

South Korea's top 20 academic institutions account for nearly 80% of all publications in the country.

Publication output and impact by sector

Academic institutions in South Korea contributed 87% of the country's publication output by sector. The top 20 academic institutions in the country by output contributed the majority of this, with 79% of the entire country's publication output, indicating a concentration of research in a few institutions. This is a higher percentage than for the publication output of the other five comparator countries' top 20 academic institutions (Figure 2-3 left). Unsurprisingly, these institutions also had a higher impact; however, the impact gap between the top institutions and the rest was smaller for South Korea compared to some other countries, such as the United States or the United Kingdom (Figure 2-2 right). This means that South Korea had a greater concentration of impactful work in fewer top institutions.

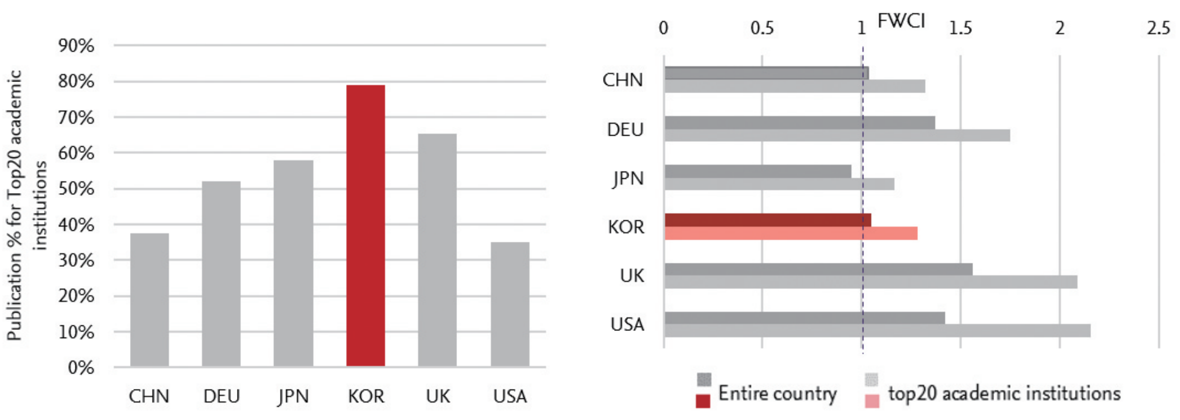


FIGURE 2-2
South Korea's top 20 institutions' publication output share (left) and FWCI (right) compared with China, Germany, Japan, the United Kingdom, and the United States, 2015–2019
Source: SciVal, August 2020

Chapter 3

Knowledge transfer

3.1 Academic–corporate collaboration output and impact

South Korea has a strong corporate sector, and co-publications with the sector also show strong scholarly impact.

Academic–corporate collaboration benchmark

Academic–corporate collaboration is defined as a publication in which at least one author is affiliated with a corporation and at least one author is affiliated with an academic institution.[5] This indicator is only one of several aspects measured for the degree of collaboration between academia and industry; others include contract research, joint patenting, technology licensing, and researcher mobility across sectors.

Academic–corporate collaboration outputs are usually smaller compared with overall publications outputs; therefore, articles with hyper-authorship tend to have a more prominent effect on the impact of a corpus. This chapter's analysis removed articles that had more than 100 co-authors and/or 30 co-countries.[6] These types of articles occur at 1.6% for the six comparator countries in average.

Somewhat surprisingly, given the overall strong R&D performance of the South Korean corporate sector in comparison with the selected countries, South Korea had a slightly lower academic–corporate collaboration share among its total scholarly output. Still, its share (5%) was substantially higher than the global average of 2.9%. This is mentioned as a reminder that simply looking at academic–corporate co-publications will not give the complete picture of collaborations; furthermore, the difference in industry structure between the comparator countries will play a role—for example, if more collaborative research is published in the Life Sciences compared to Engineering.

[5] A publication either exhibits academic–corporate collaboration, or it does not. This assignment is made based on the organization type with which Scopus tags each affiliation

[6] https://www.natureindex.com/news-blog/paper-authorship-goes-hyper

Looking at the scholarly impact of academic–corporate collaboration, South Korea followed the general trend of a higher FWCI of academic–corporate publications compared to publications overall. South Korea's average FWCI for publications with academic–corporate collaboration was 1.8, which is higher than both the global average and its overall FWCI (1.1) (Figure 3-1 top). Furthermore, South Korea's international academic–corporate collaborations attained the highest FWCI (2.9) among comparator countries (Figure 3-1 bottom left).

Most of South Korea's academic–corporate collaborations were national, accounting for 56% of those publications. This is a trend shared by the other Asian comparators in this report—both China and Japan had a higher share of national academic–corporate publications than international ones, at 57% and 54% respectively (Figure 3-1 bottom right). The overall international reach of US institutions and the collaborations between European countries, such as within the framework programs, may be one of reasons for this difference.

Of further interest is that the highest scholarly impact, as measured by the FWCI, resulted from academic–corporate collaboration with an international partner in the Medicine subject area, indicating that these collaborations generated the largest scholarly interest overall.

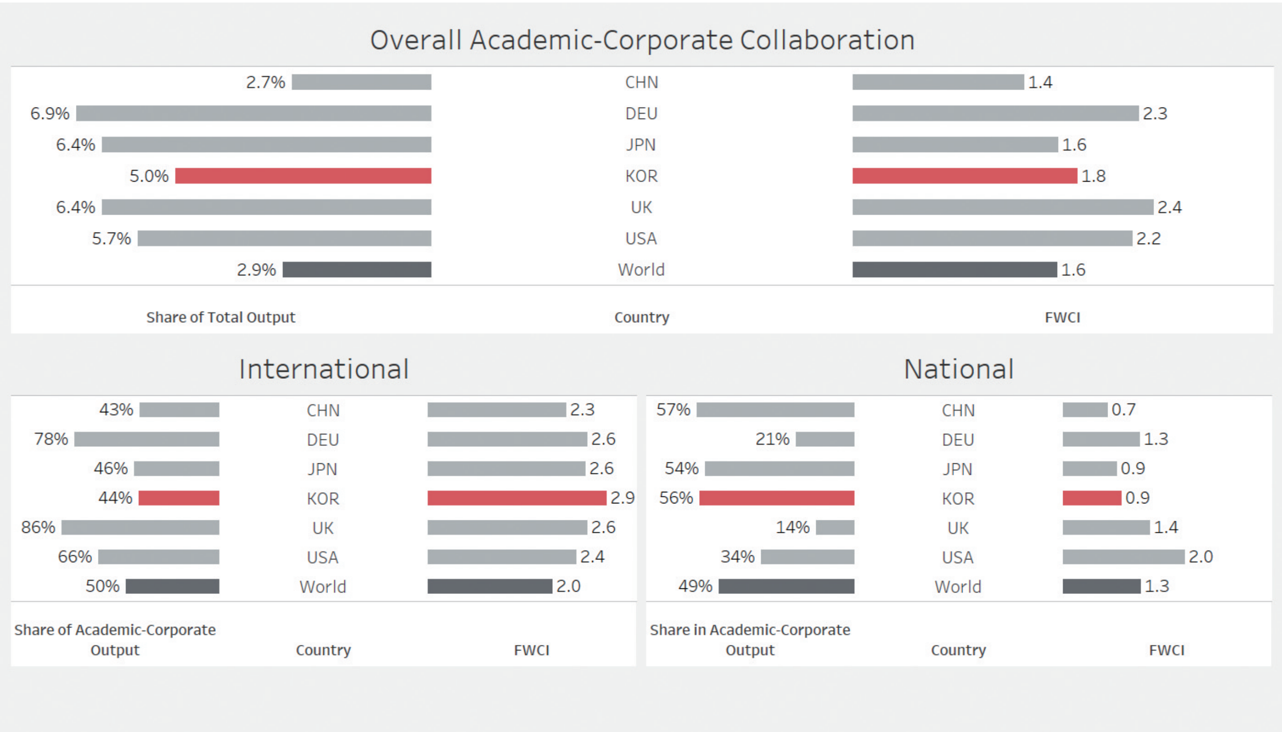


FIGURE 3-1

Academic–corporate collaboration output share and associated FWCI for comparator countries and the world, 2015–2019. Top panel shows the overall collaboration and bottom panel shows collaboration disaggregated at the national and international level

Source: Scopus, August 2020

Subject distribution of academic–corporate collaboration

Figure 3-2 shows the top 6 (by scholarly output) ASJC27 subject areas' distribution for South Korea and comparator countries over the study period. South Korea's academic–corporate collaboration was concentrated in Engineering, followed by Medicine, Materials Science, and Computer Science. China and Japan, the Asian comparators in this report, also had a high share in Engineering. China's top subjects do not include the Medicine subject area, but the Energy area featured in its top three. This different subject distribution is unique among the comparator countries. The Europe comparators, Germany and the United Kingdom, along with the United States, had the highest share in Medicine instead of Engineering, which shows a clearly different industry structure between Eastern and Western countries. It also explains why Asian countries showed a lower international collaboration share compared to Western countries in academic–corporate collaboration, since the Medicine area tends to involve more extensive international collaboration.

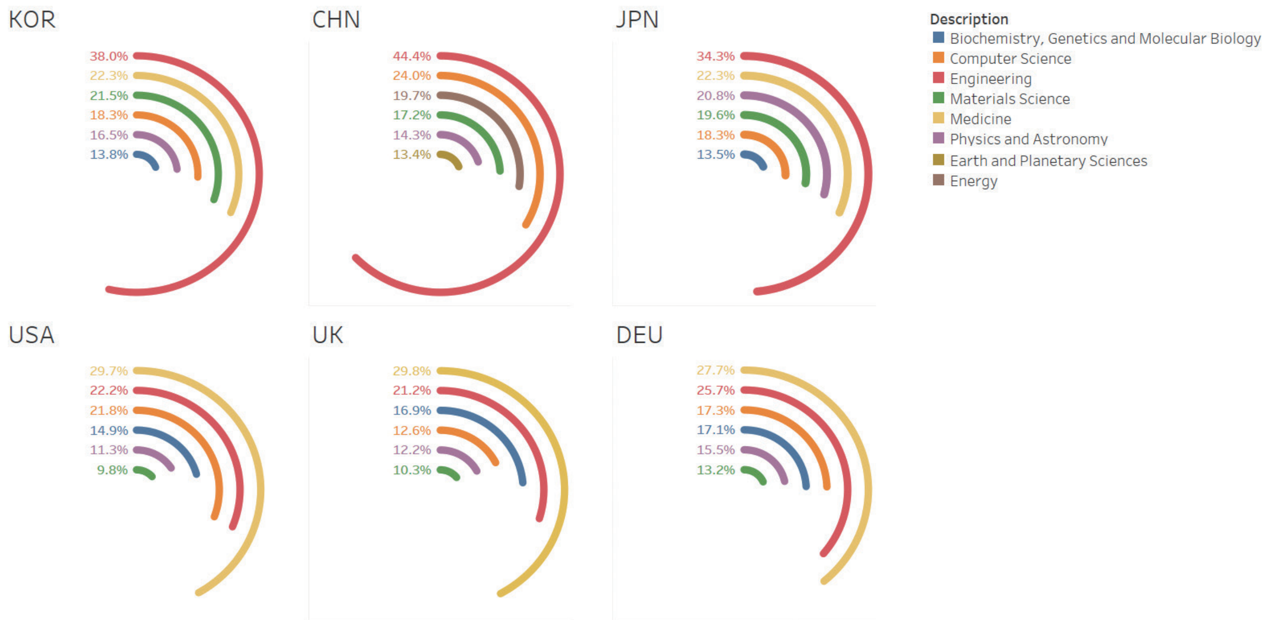


FIGURE 3-2

Top 6 subject areas for South Korea and comparator countries' academic–corporate collaboration, 2015–2019

Source: Scopus, August 2020

3.2 Academic–corporate collaboration network

South Korea's academic–corporate collaboration network is dominated by Samsung.

South Korea's worldwide collaboration network in academic–corporate co-publications

To better understand how South Korean institutions link with respect to academic–corporate co-publications, we provide a network analysis of the collaborations. For policymakers and entities seeking collaborations with South Korea, this may provide interesting perspectives with respect to entry points for collaborations.

Figure 3-3 represents the global academic–corporate collaboration network of South Korea's institutes. In order to focus more on the influential institutes in the collaboration network, each node only considers institutes with 500 or more academic–corporate collaborative publications during the 2015–2019 period. Each edge only considers instances of 50 or more bilateral co-authored publications during the same period.

There are two clusters in the network. One cluster is centered around Samsung, which has extensive collaboration with South Korean universities, including Sungkyunkwan University, Seoul National University, Hanyang University, University of Ulsan, Kyung Hea University, Korea University, and Korea Advanced institute of Science and Technology (KAIST). This cluster also contains corporates such as LG Corporation, SK Corporation, and Korea Electric Power. The institutes within this cluster have more intensive connections with each other, which also indicates more national collaboration. As noted in the previous section, these national collaborations occurred most frequently in the Engineering area during the study period. The densest co-publication activity happened between Sungkyunkwan University and Samsung, due to their close strategic alliance.

The other cluster comprises Pusan National University, Yonsei University, Inha University, and Konkuk University. These four universities had relatively higher international collaboration compared to the other institutes during 2015–2019, and their international collaboration was focused more toward Europe, with a higher output in the Medicine area. The international collaboration of these universities contributed to the overall impact of South Korea's academic–corporate collaboration.

The figure also shows that South Korea's institutes have established collaborations with top institutes worldwide, including Harvard University, Stanford University, and Johns Hopkins University in the United States, the University of Tokyo and Kyoto University in Japan, CNRS in Europe, the Chinese Academy of Sciences in China, University of Cape Town in Africa, the University of Adelaide in Oceania, and so forth.

In general, the two clusters indicate that South Korea's academic–corporate collaboration has been centered on Samsung and several top universities and that the collaboration has been more national than international.

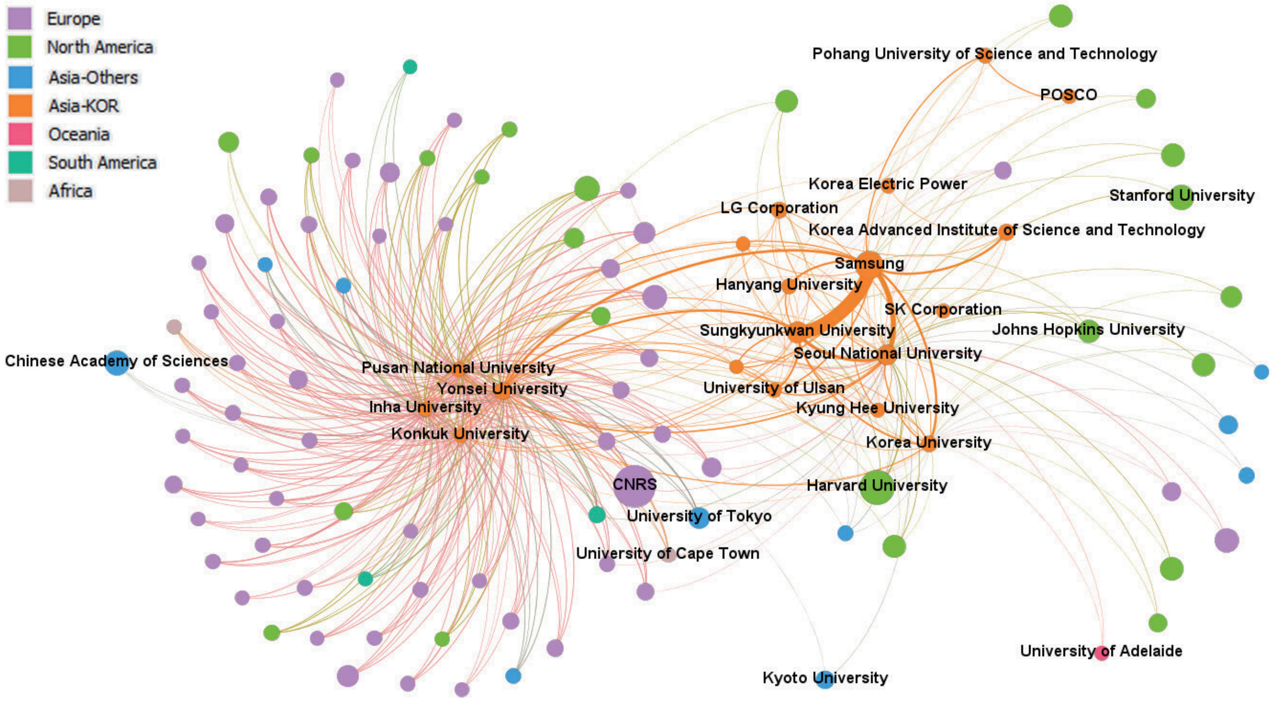


FIGURE 3-3
South Korea institutes' academic–corporate collaboration network worldwide, 2015–2019
Source: Scopus, August 2020

As a general overview, more research institutes have been involved in collaboration than corporates. The academic sector collaborated more extensively than the corporate sector and played a bridging role to connect the network. Corporates have been more peripheral in the network, which indicates a less intense collaboration.

3.3 Academic–corporate collaboration with top GII countries

Collaborating with South Korea results in higher impact for top Global Innovation Index countries in academic–corporate collaboration, indicating collaboration with South Korea is mutually beneficial.

Academic–corporate collaboration impact within top Global Innovation Index countries

In the previous section we noted that while most of South Korea's large conglomerates, such as Samsung, have been engaged in more national academic–corporate collaboration, academic institutions have had a larger share of international academic–corporate collaboration. This section unpacks the international collaborations further by looking at subject areas, showing that countries engaged in academic–corporate collaboration with South Korea benefit from the experience.

In order to provide a broader perspective of South Korea's international collaborations with leading innovators, we have chosen to look at South Korea compared to countries listed in the Global Innovation Index (GII), the annual ranking of countries by their capacity for, and success in, innovation. The GII is published by Cornell University, INSEAD, and the World Intellectual Property Organization, in partnership with other organizations and institutions. South Korea ranked 11th in the GII 2019.[7]

Figure 3-4 displays the FWCI and scholarly output of academic–corporate collaboration within the top 12 GII countries.[8] What comes out as a highly interesting result, which deserves to be analyzed in more detail, is that South Korea had a relatively smaller output with a relatively higher FWCI than other countries within the collaboration matrix. This may indicate that academic–corporate collaborations with South Korea benefit both sides, and that South Korea is a potentially beneficial collaborator for the GII countries. To understand more potential reasons for this, in the next two sections we will look further into the areas in which this collaboration takes place.

[7] https://www.wipo.int/global_innovation_index/en/2019/

[8] The analysis does not consider Israel, Ireland, and Singapore from the top 15 GII countries due to there being too few academic–corporate collaboration publications for these three countries

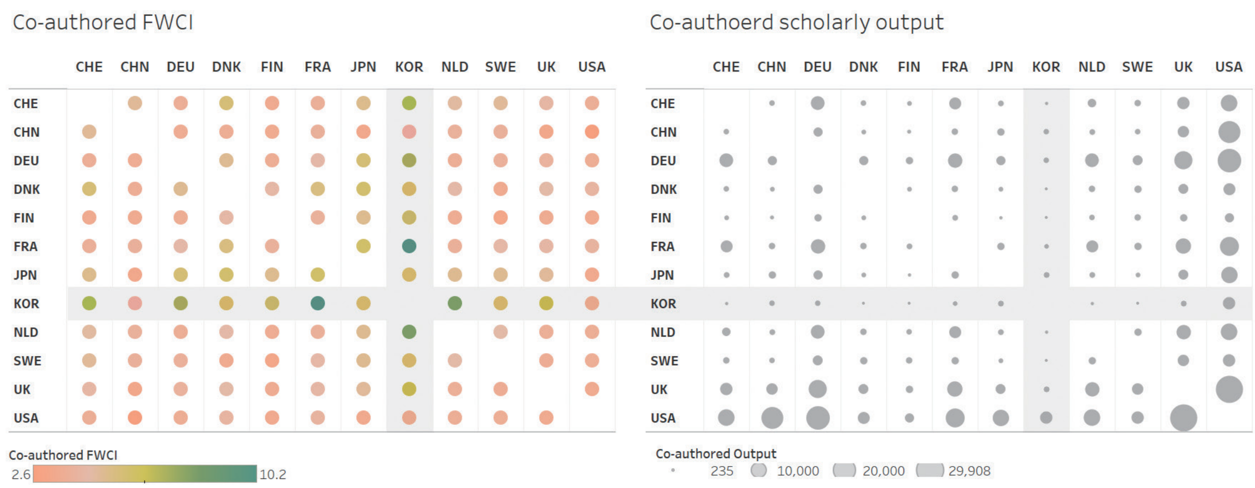


FIGURE 3-4
Academic–corporate collaboration FWCI (left) and scholarly output (right) within the top 12 GII countries, 2015–2019. GII countries are Switzerland (CHE), China (CHN), Germany (DEU), Denmark (DNK), Finland (FIN), France (FRA), Japan (JPN), South Korea (KOR), the Netherlands (NLD), Sweden (SWE), the United Kingdom (UK), and the United States (USA)
Source: Scopus, August 2020

Academic–corporate collaboration subject area distribution between South Korea and top GII countries

In academic–corporate collaboration over the study period, South Korea's collaboration with European countries focused mainly on Medicine and involved Switzerland, Germany, France, the Netherlands, Sweden, and the United Kingdom (Figure 3-5). These collaborations show a strong presence by some institutions in South Korea's academic sector, such as Seoul National University and Sungkyunkwan University. On the other hand, South Korea's collaboration with Denmark concentrated mostly around Biochemistry, Genetics and Molecular Biology, in which KAIST was the most frequent contributor. South Korea's collaboration with Finland concentrated on Engineering, in which the most frequent contributors included Samsung from South Korea and Nokia and Aalto University from Finland. The particular case of Finland may reflect the strong role Nokia has played as an ICT company in the Finnish innovation ecosystem.

In Asia, South Korea's collaboration with China was mostly in Engineering. For South Korea–China collaborations, the most frequent collaborators were Samsung from South Korea and Huawei Technologies Co., Ltd. from China. Collaboration with Japan was mostly in Medicine, in which the most frequent contributors were Seoul National University and Sungkyunkwan University from South Korea, and Kindai University, National Cancer Center Hospital East, and Aichi Cancer Center Hospital from Japan.

For academic–corporate collaborations between South Korea and the United States, most were in Engineering, with Samsung, KAIST, Seoul National University, and LG Corporation being the most frequent collaborators from South Korea, and Intel and IBM the most frequent collaborators from the United States.

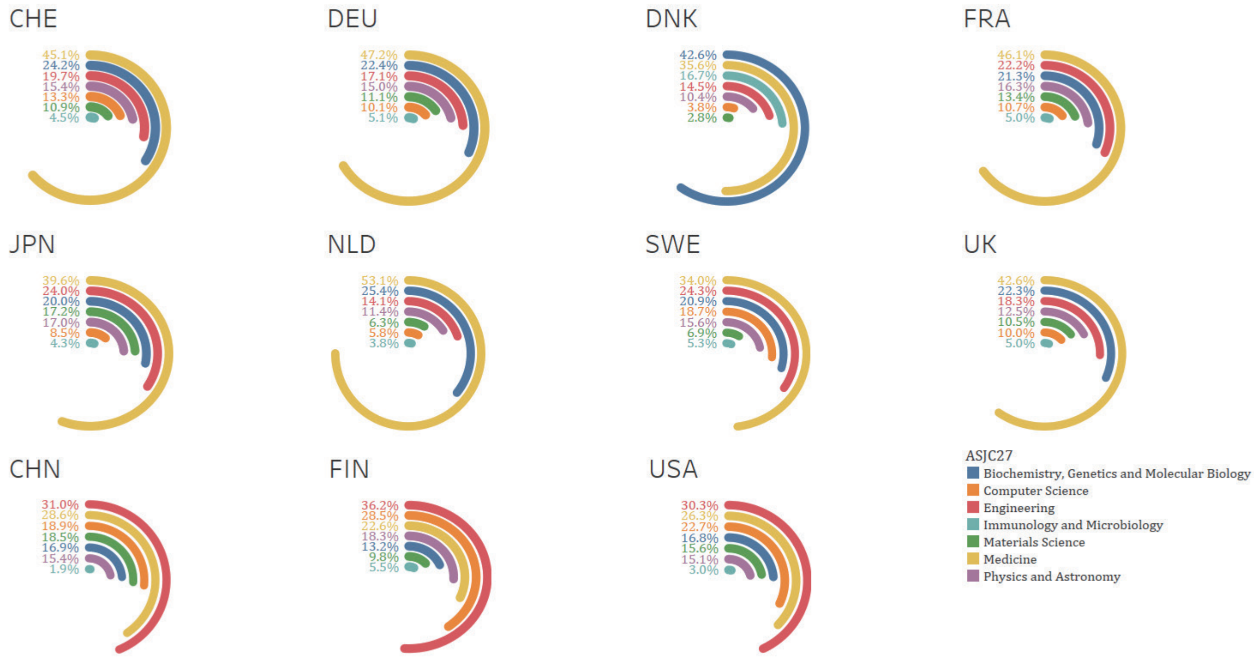


FIGURE 3-5

Main ASJC27 subject areas for academic–corporate collaboration between South Korea and top GII countries, 2015–2019

Source: Scopus, August 2020

Keyphrase analysis of academic–corporate collaboration between South Korea and GII countries

While the section above gave an overview of the collaborations (and many quite intuitive ones given the industrial structure of these countries—for example, strong ICT sector, or strong life science sector) it is of interest to probe one level deeper to understand which are the key areas of collaboration. To do this we used the Elsevier Fingerprint Engine to extract distinctive keyphrases within the research area of collaboration.[9] Highly relevant keyphrases are those that occur frequently in the research area. Due to the space limitations of this report, this keyphrase analysis gives only a snapshot of collaboration. A more detailed analysis should also investigate areas of co-funded research between NRF and GII counterparts, as well as other funded collaborations.

Figure 3-6 shows the top 10 keyphrases by relevance for academic–corporate collaborations between South Korea and the top GII countries. Keyphrases in Medicine account for the majority of collaborations between South Korea and Germany, France, the Netherlands, and Switzerland. These keyphrases are mainly terms related to cancer treatment such as “Afatinib”, “Sorafenib”, “Pembrolizumab”, “Everolimus”, “Fulvestrant”, and the like. Other medication treatment terms related to caries also appears in collaboration with the Netherlands, such as “Quantitative Light-induced Fluorescence” and “Caries”. In addition, two Genetics research terms appear in collaboration with Netherlands: “Twins” and “Genome-wide Association Study”. Keyphrases in collaboration with China, Japan, and the United Kingdom show different medication treatment terms related to cancer: “Epidermal Growth Factor Receptor”, “Non-small Cell Lung Carcinoma”, “Osimertinib”, and “Crizotinib”.

[9] https://service.elsevier.com/app/answers/detail/a_id/27763/supporthub/scival/kw/+keyphrases/

Keyphrases in collaboration with Denmark most focus on the Genetics area—for example, "Cricetulus", "Metabolic Engineering", "Genome", "Clustered Regularly Interspaced Short Palindromic Repeat", and "Gene Editing".

Keyphrases in Engineering and Material Science are also observed mainly within these collaborations, such as "Electrode" with Germany, "Transistor" with France, "Perovskite Solar Cell" with Switzerland, and "Graphite" with China. More keyphrases in the Engineering and Material Science areas appear in collaboration with Sweden and the United States—for example, "Millimeter Wave", "Silicon Photonic", "Voice", and "Frequency Reuse" with Sweden, and "Millimeter Wave", "Power Amplifier", and "Random Access Memory" with the United States. Different keyphrases in collaborations with Finland appear in the Engineering area, such as "Channel Model", and in the Computer Science area, such as "Internet of Things" and "Edge Computing".

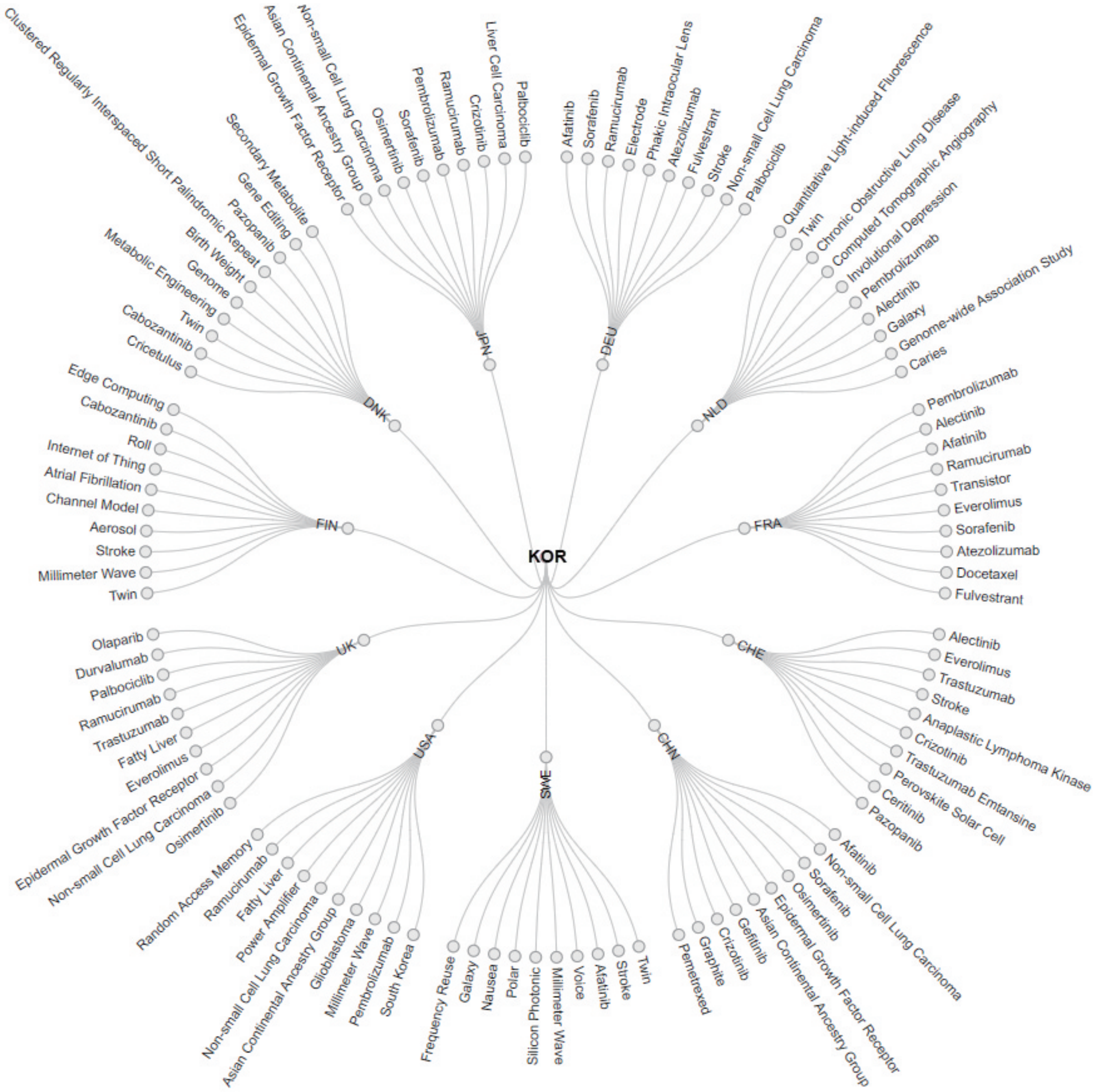


FIGURE 3-6

Top 10 Keyphrases by relevance for academic–corporate collaboration between South Korea with top GII countries, 2015–2019

Source: Scopus, August 2020

Chapter 4

Patenting activity

4.1 Setting the stage

Empirical research has shown that patents are frequently a good predictor of economic performance and a proxy for innovation power.

Among the available indicators of technology output, patent indicators are probably the most frequently used. Patent-based statistics have several uses. They allow for measuring the inventiveness of countries, regions, firms, or individual inventors, under the assumption that patents reflect inventive output and that more patents mean more inventions. Empirical research has shown that patents are frequently a good predictor of economic performance.

Various patent indicators were developed and empirically tested within technology intelligence-related patent analytics to achieve the previously stated purposes. Traditionally, counts of patenting activity or portfolio sizes—that is, the number of patents filed, applied for, or granted—were benchmarked to competitors' figures or incumbent technologies. This indicates, however, only the quantity of patents, not the actual value or the quality of the inventions.

There are various possible approaches to assessing the value of patents (or the inventions behind them).

Forward citations refer to references received by patents from future patents and are indicative of a technology's impact on subsequent technologies. In terms of technology intelligence, the more citations certain technologies receive—or rather, that their patents receive—the more likely it is that the underlying technology finds widespread application.

Patent families are "a set of either patent applications or publications taken in multiple countries to protect a single invention by a common inventor(s) and then patented in more than one country" (European Patent Office, 2017). Patent families refer to technologies' geographical scopes of protection. Similar to citations, the more jurisdictions or geographical spheres that are protected, the more likely it is that the underlying technology finds global application.

In this report, we combine both approaches—combining the size of a patent portfolio of a country with an approximated value of the underlying patents. We utilize indicators developed by PatentSight, a sister company to Elsevier within RELX, focusing on patent analysis.

The indicator Competitive Impact measures the quality or usefulness of the patent to create a sustainable competitive advantage. Thus, both the potential to create competitive advantage through important technologies (the impact of the patents as indicated by forward citations) and the potential to exploit that competitive advantage in large markets (the effectiveness of the patents to avoid imitation as patenting in various markets) must be considered simultaneously.

High citation impact combined with a large market coverage yields highly competitive impact and advantage for the patent owner. A technology, however, is worth much less without a large market to exploit it. Likewise, broad international patent protection for weak technologies are of lower value too.

The sum of all the competitive impact scores of all patents in a country's patent portfolio is calculated as the Patent Asset Index (PAI). This indicator depicts the overall strength of a patent portfolio by accounting for impact, coverage, and portfolio size.

It needs to be noted, however, that patenting may have certain drawbacks. Whereas patent applications are an indicator of successful research—notably in a particular line of research or in a program—patents do not reflect all of the research and innovative efforts behind an invention. Conversely, an invention covered by a patent (a new product or process) need not actually be industrially applied. It is reported that many patents are never implemented, because the inventor realizes that the invention does not have sufficient economic value or that a superior invention can be marketed more rapidly.

4.2 South Korea's patent portfolio

South Korea's patent portfolio has been steadily growing in terms of both quality and quantity.

To provide a sense of the innovative power of South Korea against the global comparators, we assessed the innovation strength of South Korea and the comparators, based on their respective patent portfolios for the period 2000–2019.

The United States is the second-strongest country on innovation by PAI, recently having been overtaken by China. Among the comparators, South Korea ranks fifth, between Germany and the United Kingdom.

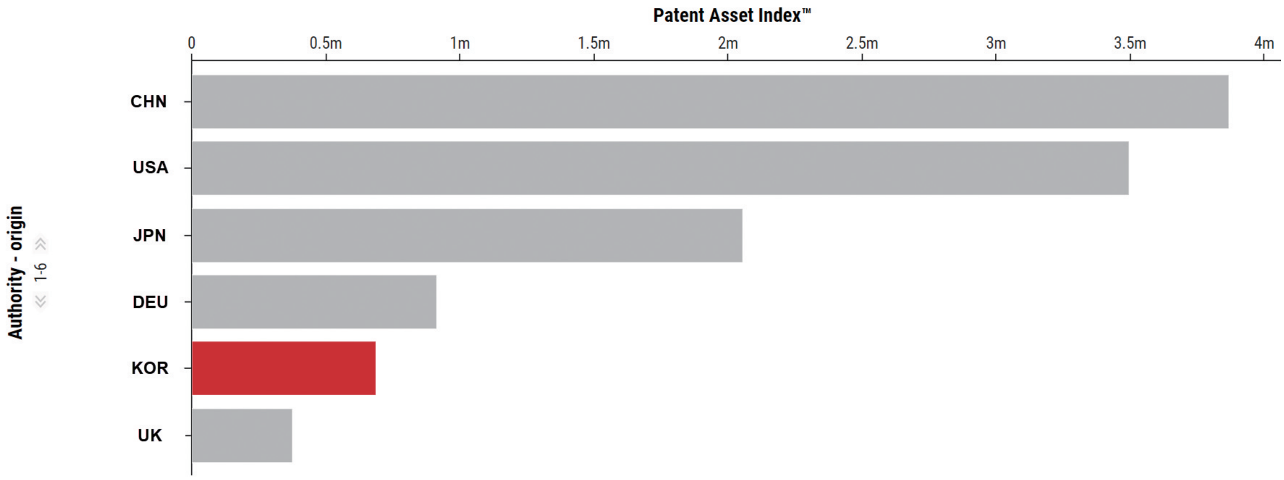


FIGURE 4-1
Patent Asset Index of South Korea and comparators, all active patents 2019
Source: PatentSight, September 2020

The PAI, however, is a composite indicator, based on the portfolio size (number of patents) and the value of the patents in a portfolio. Therefore, it is size dependent—with large countries usually being more prolific. For this reason, we assessed the comparators in Figure 4-2, which depicts the number of patent families (portfolio size) against the quality of the patents (competitive impact). While the United States still leads in terms of average quality of the peer group, China is by far the leader for patent output. This trend is similar to research publications, in which China has overtaken the United States as the country with the largest scholarly output, and this at the same time as its scholarly impact has increased.

When analyzing patent portfolios and their development, China was a latecomer to the innovation activities, starting at a similar level of technology capability as South Korea 20 years ago. Although China has achieved significant growth in terms of filings, the overall impact of its patent portfolio has remained almost stable. Japan used to have a much larger portfolio but has seen a general shift away from quantity to quality, with many companies pruning their portfolios. Japan's portfolio size decreased by around 50% from 2000 to 2019. Germany has gradually increased its portfolio size, although on a relatively low level. South Korea has filed almost twice the number of patents as Germany and nine times more than the United Kingdom. The United Kingdom's patent portfolio size remained stable across the full period.

The Competitive Impact of patents from Germany, Japan, the United Kingdom, and the United States has declined in recent years, however. China only shows growth of portfolio size, without increasing the quality of its patents. South Korea is the only country of the peer group whose patent portfolio has been steadily growing in terms of both quality and quantity simultaneously.

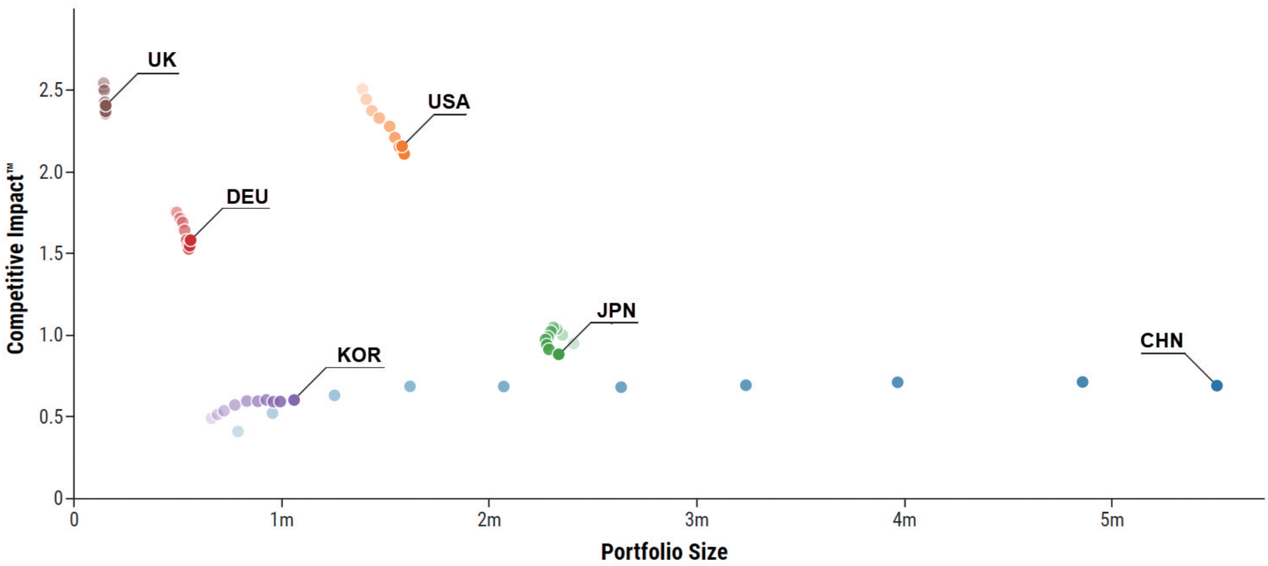


FIGURE 4-2

Trend of South Korea's and comparators' competitive impact and portfolio size, 2000–2019. Shading of bubbles depicts year of active patent families: the lightest shade indicates the year 2000 and the darkest shade 2019

Source: PatentSight, August 2020

With South Korea's growth of portfolio strength in terms of quality and quantity, its share of global innovation strength has also been continuously increasing over time (Figure 4-3). In the past, the United States and Japan used to have dominant shares on innovative capability, but their global share of innovative strength has been decreasing due to other authorities actively participating in innovation activities—for example, South Korea and China. China has significantly increased its global share on portfolio strength over time, even if this has been mainly contributed to by quantity. Other than China, South Korea's growing share of global innovative strength has been a function of both quantity and quality. No other comparator grew its share in both dimensions; in fact, in these indicators South Korea overtook the United Kingdom in 2010.

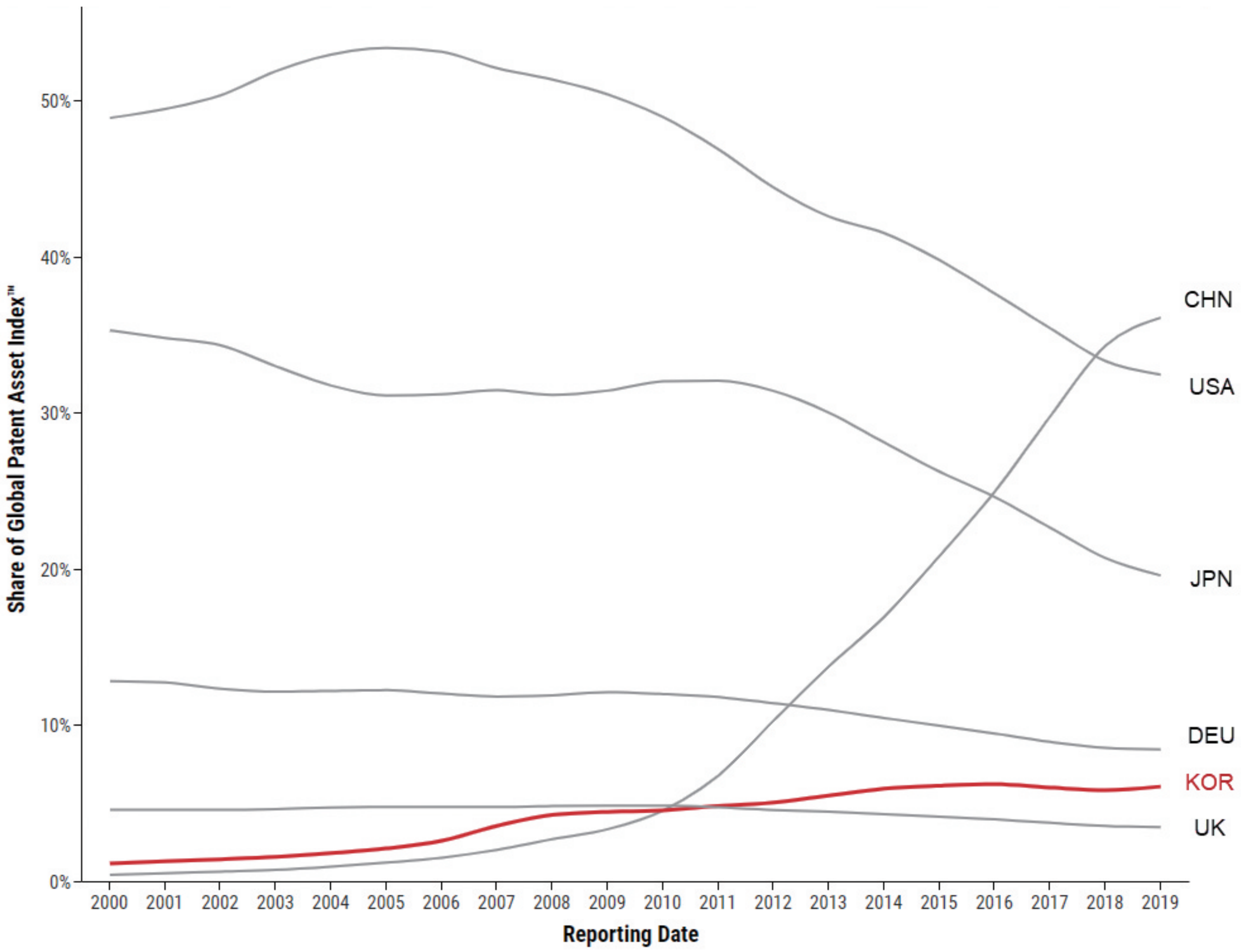


FIGURE 4-3
Trend of South Korea's and comparators' share of global Patent Asset Index, 2000–2019
Source: PatentSight, August 2020

4.3 Technology field

South Korea’s current core technology fields are “Semiconductors” and “Electric power” within Electronics. Academic and governmental research institutes focus on a slightly different set of technologies than corporates.

Each country has a different technology focus by history or strategic choice and they would most likely consider different subject areas as a particular. Similar to subject areas for publications, patents can be filed in multiple subject areas. As a categorization system based on, for example, the Cooperative Patent Classification or the International Patent Classification (IPC) will most likely show patents in multiple sections or classes, this analysis uses a new approach called technology clusters.

All patents are hierarchically clustered using unsupervised machine learning on the patent text data and patent meta data, creating sets of similar patent families. These clusters comprise four levels of hierarchy. Since each patent family in our database belongs to exactly one technology cluster on each level, portfolios can be analyzed without having to pay attention to technology overlaps (e.g., as in IPC classifications).

Figure 4-4 displays the PAI of the active patent portfolio of the comparators for the highest aggregation level of technology clusters. The bubble size correlates with the PAI. While China has its strength in “Information”, followed by “Telecommunications”, Japan is particularly strong in “Electronics”. South Korea, with its smaller portfolio and only growing impact, has strength areas in the fields of “Electronics”, “Information”, and “Telecommunications”, whereas “Agriculture” and “Nutrition” are not the focus of national innovation.

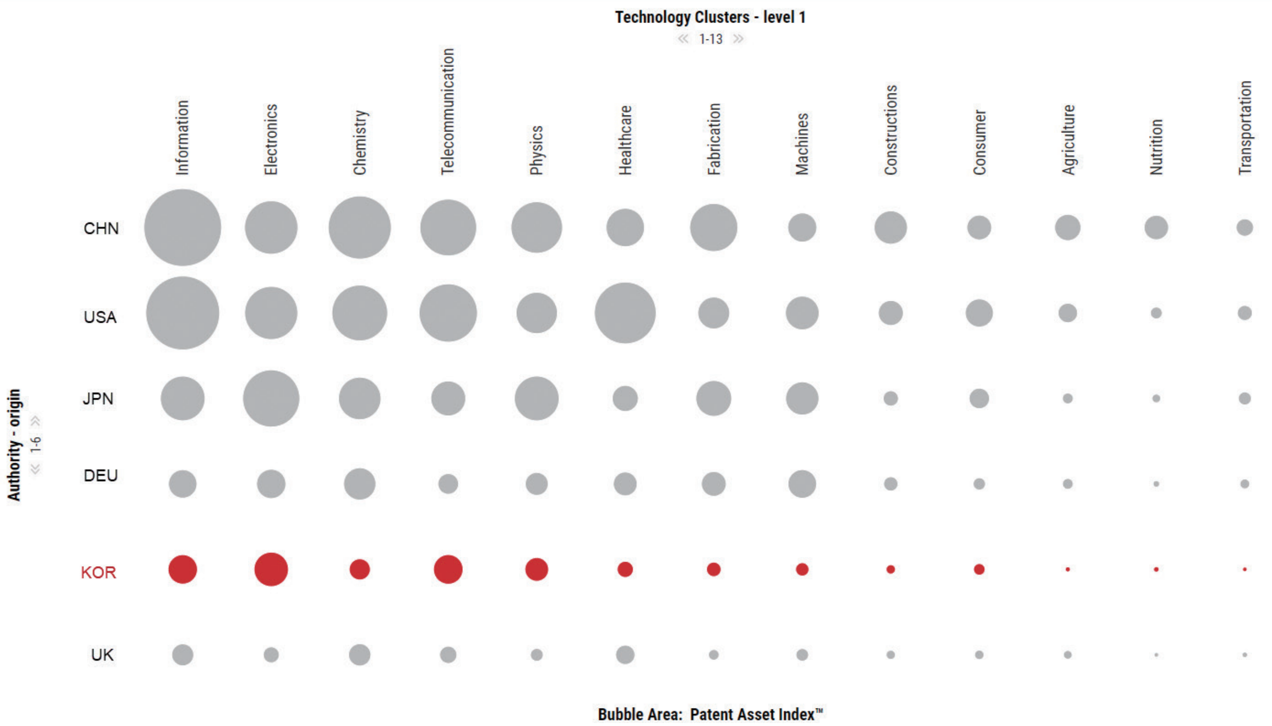
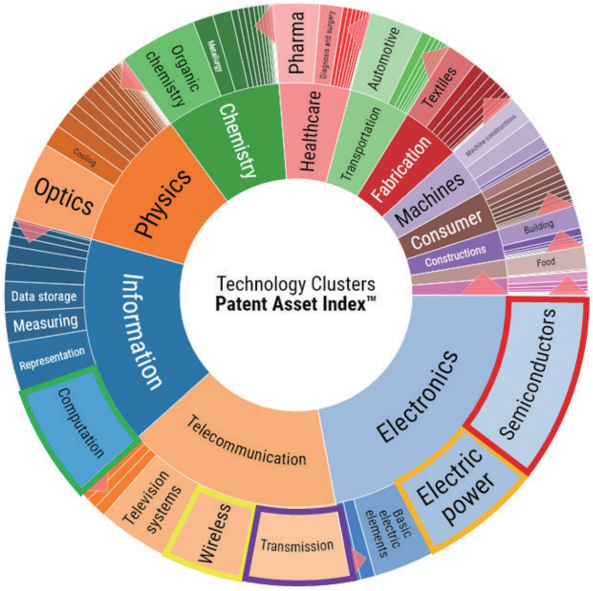


FIGURE 4-4

South Korea's and comparators' technology cluster (level 1) distribution by Patent Asset Index, based on patent families active in August 2020

Source: PatentSight, August 2

Looking in more detail at the technology fields of South Korea (Figure 4-5), its core technology fields in the study period were "Semiconductors" and "Electric power" within Electronics. These accounted for nearly 20% of national technological strength—or in other words, both areas comprised 19% of the PAI while accounting for only 11% of the national portfolio. Other strength areas with a higher share of PAI than share of portfolio size were within the areas of "Computation", "Transmission", and "Wireless"—intuitively related to strong drivers of innovation in South Korea, notably Samsung and LG.



Technology Clusters (Level 2)		Patent Asset Index™	Portfolio Size
Electronics > **Semiconductors**	●	11.3%	6.2%
Electronics > **Electric power**	●	7.3%	4.9%
Information > **Computation**	●	7.0%	4.7%
Telecommunication > **Transmission**	●	6.8%	3.9%
Telecommunication > **Wireless**	●	5.1%	2.1%

100% = South Korean innovation's Total Patent Asset Index™, Total Portfolio Size

FIGURE 4-5
South Korean technology cluster (level 2) distribution by Patent Asset Index and portfolio size, based on patent families active in August 2020. Slice size represents the corresponding technology cluster's Patent Asset Index
Source: PatentSight, August 2020

It is interesting to dive into the participation of different sectors performing R&D. Assessing the patent portfolio of South Korea's research institutions in contrast to the patent portfolio of the corporate sector reveals interesting information about the innovation focus areas of the various stakeholders. Figure 4-6 investigates the top 50 corporates and research institutes by respective portfolio size.

"Telecommunications", "Electronics", "Information", "Chemistry", and "Physics" are the main common focus areas between the two sectors; research institutes have a sizable portion of focus in the "Healthcare" area, especially within fields such as "Pharma". Also, in the "Information" area, research institutes focus on a slightly different set of technologies, with fields such as "Analyzing material" receiving greater attention. This can be explained with some analysis, which shows that within academic–corporate collaborations the academic sector has more output in the Medicine subject area than the corporate sector does. This may suggest there's knowledge transfer between research publications and patents in the Medicine and Pharmaceutical fields. However, it should be noted that corporates play a major role in patenting activities, and therefore they account for around 70% of the total national patent portfolio.

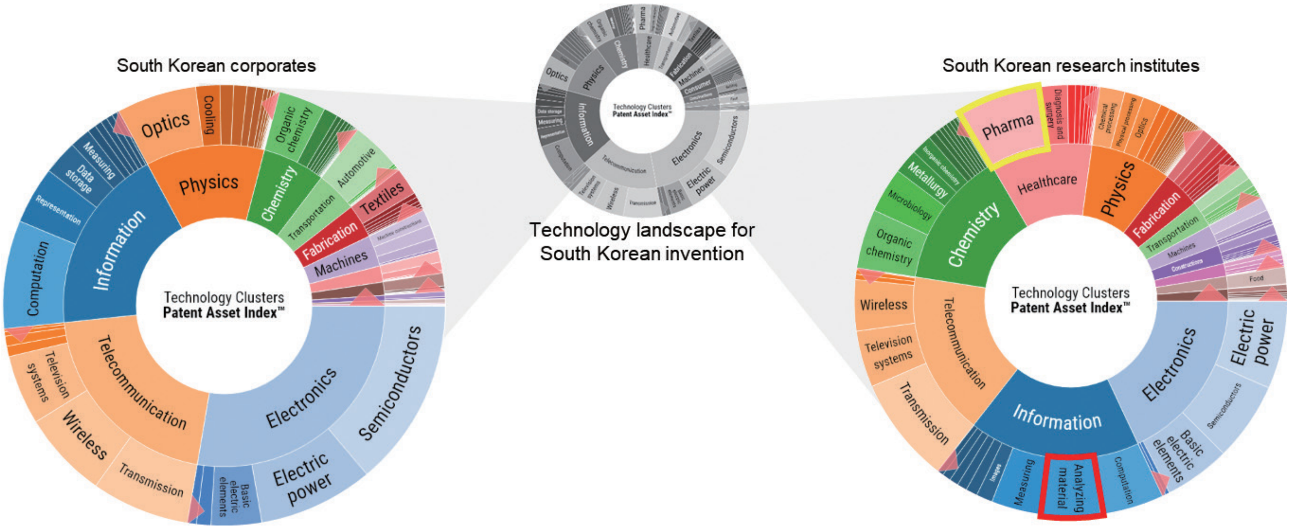


FIGURE 4-6

South Korean corporates and research institutes technology cluster (level 2) distribution by Patent Asset Index, based on patent families active in August 2020. Slice size represents the corresponding technology cluster's Patent Asset Index

Source: PatentSight, August 2020

In conclusion, in terms of patent portfolios around activities toward innovation, South Korea's strong position is no less than remarkable. Interestingly, by academic–corporate collaboration volume Samsung was by far the strongest player, but in patenting activities, although Samsung also is the leader, its position is less dominant. South Korea's research institutes also contribute certain amounts of patent activities and they are reducing its gap with Samsung. The implications of this with respect to the current and future research, patents, and product portfolios of South Korean companies would be worth analyzing in further detail.

Conclusion

The aim of this report was to present some key insights around the South Korean research and innovation system in comparison with other countries in recent years.

We have seen that South Korea has been investing heavily in R&D, both overall and in business R&D, ahead of all comparators in the report. The scholarly output and impact of the country has increased, albeit slowly compared to the benchmarked countries. This can be related to the R&D conducted by business, which is less likely to result in publications as this is not the primary goal of industry.

A different view is observed for patenting activities. South Korea's patent portfolio grew in terms of both quality and quantity, and while other countries led in portfolio size (China) or competitiveness (the United Kingdom), none of the comparators grew in both dimensions other than South Korea.

A discussion point emerging from this report is whether academic–corporate collaboration has been explored to the fullest potential in South Korea. While South Korea's share of academic–corporate collaboration, as measured in co-publications, is significantly above the global average, it is less than most of the other comparators, other than China. The collaboration between the two sectors mainly occurs at the national level, driven by large conglomerates such as Samsung. However, despite a smaller share, internationally oriented cross-sector collaboration has benefited both South Korea and other countries.

There is also a slight differentiation in focus: where, overall, South Korean research is highly focused on Chemical Engineering, Materials Science, and Chemistry, with scholarly impact higher than the global average, academic–corporate collaboration is mostly focused on Engineering, Medicine, and Computer Science, as well as Materials Science. This may suggest that South Korea has unexplored potential areas for further academic–corporate collaboration, such as Chemical Engineering or Chemistry. A similar observation can be made for patenting activity. While "Telecommunications", "Electronics", "Information", "Chemistry", and "Physics" are common fields of patenting for both research institutions and corporate sectors, research institutes also have patenting activities in Medicine and Pharma, which were the focus of international cross-sector collaboration.

The brief findings of this report suggest that there may be room for expanding the fields of national cross-sector collaboration while expanding the overall breadth of international cross-sector collaboration.

Appendix A

South Korea's top academic and corporate institutes

Top 20 South Korean academic institutions by scholarly output

Institution	Scholarly Output	FWCI	Citations	Citations per Publication
Seoul National University	50,724	1.49	579,254	11.4
Yonsei University	29,025	1.32	299,441	10.3
Sungkyunkwan University	27,227	1.46	332,260	12.2
Korea University	26,633	1.47	303,062	11.4
Korea Advanced Institute of Science and Technology	20,473	1.31	216,344	10.6
Hanyang University	19,556	1.27	220,818	11.3
Kyung Hee University	16,857	1.4	178,284	10.6
Kyungpook National University	15,427	1.12	134,570	8.7
Pusan National University	15,182	1.1	139,975	9.2
University of Ulsan	14,044	1.36	150,283	10.7
Chonnam National University	12,345	1.17	117,629	9.5
Chungnam National University	10,917	0.87	73,135	6.7
Catholic University of Korea	10,801	0.98	81,348	7.5
Chung-Ang University	10,561	1	77,237	7.3
Jeonbuk National University	10,449	1.11	97,469	9.3
Pohang University of Science and Technology	10,437	1.43	137,324	13.2
Konkuk University	10,299	1.06	91,984	8.9
Inha University	9,279	1.01	77,768	8.4
Ewha Womans University	8,423	1.1	85,333	10.1
Yeungnam University	8,167	1.2	79,333	9.7

TABLE 1
South Korea's top 20 academic institutions by scholarly output, 2015–2019
Source: SciVal, August 2020

Top 20 South Korea corporate institutions by patent portfolio size

Owner	Portfolio Size	Competitive Impact™	Patent Asset Index™
Samsung	99,133	1.9	192,461
LG Electronics	45,622	1.7	75,401
LG Display	25,679	1.3	32,495
LG Chem	19,683	1.6	31,175
Hyundai Motor	27,892	0.8	21,724
Samsung SDI	8,803	1.6	13,675
LG Innotek	10,576	0.9	9,778
SK Hynix	10,821	0.8	8,859
Kia Motors	9,210	0.9	8,611
Samsung Electro-Mechanics	6,501	0.9	5,679
Posco	17,104	0.3	4,284
LS Industrial Systems	3,610	1	3,511
Samsung C&T	2,696	1.2	3,227
Hahn & Company	4,836	0.6	2,975
Halla Holdings	4,523	0.6	2,790
CJ Corporation	1,327	1.7	2,241
Amorepacific Corp.	2,876	0.8	2,223
Hyundai Mobis	4,652	0.4	2,093
Seoul Viosys	1,296	1.6	2,042
SK Telecom	7,065	0.3	2,032

TABLE 2
South Korea's top 20 corporate institutions by portfolio size, based on patent families active in August 2020
Source: PatentSight, August 2020

Top 20 South Korea research institutions by portfolio size

Owner	Portfolio Size	Competitive Impact™	Patent Asset Index™
Electronics and Telecommunications Research Institute	14,151	0.6	7,937
Korea Advanced Institute of Science and Technology	6,755	0.5	3,364
Seoul National University	6,547	0.5	3,128
Korea Institute of Science and Technology	4,067	0.6	2,359
Hanyang University	3,889	0.5	1,952
Yonsei University	5,058	0.4	1,894
Korea University	4,820	0.3	1,562
Sungkyunkwan University	3,247	0.4	1,459
Pohang University of Science and Technology	2,110	0.7	1,414
Korea Research Institute of Chemical Technology	2,346	0.6	1,303
Korea Institute of Machinery and Materials	3,866	0.3	1,083
Kyung Hee University	2,436	0.4	933
Korea Institute of Industrial Technology	3,369	0.3	862
Korea Institute of Energy Research	2,715	0.3	861
Korea Electronics Technology Institute	2,888	0.3	778
Kyungpook National University	2,800	0.2	618
Korea Institute of Geoscience and Mineral Resources	1,600	0.4	612
Korea Atomic Energy Research Institute	2,343	0.3	609
Gwangju Institute of Science and Technology	1,099	0.5	603
Sogang University	1,990	0.3	592

TABLE 3
South Korea's top 20 research institutes by portfolio size, based on patent families active in August 2020
Source: PatentSight, August 2020

Appendix B

Glossary

Author refers to any individual listed in the author byline of a Scopus-indexed publication.

Compound annual growth rate (CAGR) is defined as the year-over-year constant growth rate over a specified period. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

$$CAGR(t_0, t_n) = \left(\frac{V(t_n)}{V(t_0)}\right)^{\frac{1}{t_n - t_0}} - 1$$

where

$V(t_0)$: start value

$V(t_n)$: finish value

$t_n - t_0$: number of years

Field-Weighted Citation Impact (FWCI) is an indicator of the citation impact of a publication. It is calculated by comparing the number of citations received by a publication with the number of citations expected for a publication of the same document type, publication year, and subject. An FWCI of more than 1.00 indicates that the entity's publications have been cited more than would be expected based on the global average for similar publications; for example, 2.11 means 111% more than the world average. An FWCI of less than 1.00 indicates that the entity's publications have been cited less than would be expected based on the global average for similar publications; for example, 0.87 means 13% less than the world average. In general, the FWCI is defined as follows:

$$FWCI = \frac{C_i}{E_i}$$

with

Ci= citations received by publication i

Ei= expected number of citations received by all similar publications in the publication year plus following 3 years

When a similar publication is allocated to more than one subject, the harmonic mean is used.
To calculate mean FWCI for the publication set, we use the formula:

$$\overline{FWCI} = \frac{1}{N}\sum_{i=1}^{N}\frac{C_i}{E_i}$$

Where N = the number of Scopus-indexed publications in the publication set. FWCI is always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document ages (e.g. older documents are expected to have accrued more citations than more recently published documents), document types (e.g. reviews typically attract more citations than research articles), as well as subjects (e.g. publications in Medicine accrue citations more quickly than publications in Mathematics. FWCI is one of the most sophisticated indicators in the modern bibliometric toolkit.[10] FWCI uses an un-weighted variable 5-year window. The mean FWCI value for 2012 publications, for example, is calculated for documents published in 2012 using their citations in 2012–2017. For recent output with less than five years since publication, all citations available at the date of data extraction are used in the calculation. For instance, if an article is published in 2016, and the data are extracted in 2018, the article's FWCI is calculated using the article's 2016–2018 citations.

Full-time equivalent (FTE) of R&D personnel is defined as the ratio of working hours spent on R&D during a specific reference period (usually a calendar year) divided by the total number of hours conventionally worked in the same period by an individual or by a group. In other words, one FTE may be thought of as one person-year. Thus, a person who normally spends 30% of his/her time on R&D and the rest on other activities (such as teaching, university administration and student counseling) should be considered as 0.3 FTE. Similarly, if a full-time R&D worker is employed at an R&D unit for only six months, this results in an FTE of 0.5. It is measured by combining two variables: actual involvement in R&D activities and formal engagement based on normative/statutory working hours. FTE is a true measure of the volume of R&D and the main R&D personnel statistic for international comparisons.[11]

Gross domestic expenditure on research and development (GERD) is the total intramural expenditure on R&D performed in the national territory during a given period. GERD is calculated as the total domestic intramural expenditure on R&D during a given year divided by the GDP (i.e., the sum of gross value added by all resident producers in the economy, including distributive trades and transport, plus any product taxes and minus any subsidies not included in the value of the products) and multiplied by 100.

Gross domestic product (GDP) is an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs). The sum of the final uses of goods and services (all uses except intermediate consumption) measured in purchasers' prices, less the value of imports of goods and services, or the sum of primary incomes distributed by resident producer units.

Purchasing power parity (PPP) is the rates of currency conversion that try to equalize the purchasing power of different currencies, by eliminating the differences in price levels between countries. This indicator is measured in terms of national currency per US dollar.

Relative Activity Index is defined as the share of a country's article output in a subject relative to the global share of articles in the same subject. A value of 1.0 indicates that a country's research activity in a field corresponds exactly with the global activity in that field; higher than 1.0 implies a greater emphasis while lower than 1.0 suggests a lesser focus.

[10] Purkayastha, A., Palmaro, E., Falk-Krzesinski, H. J., & Baas, J. (2019). Comparison of two article-level, field-independent citation metrics: Field-Weighted Citation Impact (FWCI) and Relative Citation Ratio (RCR), Journal of Informetrics, 13(2), 635–642. https://doi.org/10.1016/j.joi.2019.03.012

[11] Source of Definition: OECD. (2015). Frascati Manual 2015: Guidelines for collecting and reporting data on research and experimental development

Research & development (R&D) is any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications. R&D includes fundamental research, applied research in such fields as Agriculture, Medicine, and Industrial chemistry, and experimental development work leading to new devices, products, or processes.

Researchers "are professionals engaged in the conception or creation of new knowledge, products processes, methods, and systems, and in the management of the projects concerned".[12] This definition is provided in the 2002 edition of the Frascati Manual and provided to the national statistical agencies that compile the data on research inputs made available by the OECD. This definition includes members of the armed forces who perform R&D, managers and administrators engaged in the planning and management of the scientific and technical aspects of a researcher's work, and PhD students engaged in R&D. Researchers are distinct from "authors" as defined above because they may include those who have not been listed as an author in a Scopus-indexed publication.

Top 1% most cited publications are those among the top 1% most cited based on citations of all articles published and cited in a given period. A country's number or share of highly cited articles is treated as indicative of the excellence of their research.

[12] https://stats.oecd.org/glossary/detail.asp?ID=2318

Appendix C

Patent indicators

Number of patents

A collection of patents in a particular discipline may represent part of the accumulated knowledge in science and technology within that discipline. The growth of the number of patents of a given technology provides a good indication of its state of development.

Market Coverage™

The total size of the worldwide markets in which patent protection exists. The more patents a patentee (in this case an institution or a country the patent owner is affiliated with) owns in important markets, the more valuable the patents are estimated to be. This is because innovators spend more effort and resources on protection in multiple (global) markets via patents if they believe an invention is more valuable.

Market Coverage is calculated based on granted and pending patents, hence valid patents per country adjusted for each market's size, as opposed to simple country counts. The size of each market is estimated using the sum of countries' gross national income (GNI) relative to the US GNI as the largest global economy. A Market Coverage of 2 means that the protected markets are in total twice as large as the US market alone.

Technology Relevance™

The number of forward citations a patent receives, accumulates over time and appears to be correlated to the patent's (i.e., its underlying invention's) technological impact. Citations are divided into two main classes: backward citations and forward citations. Backward citations are those earlier patents (or publications) cited by a focal patent—often used as measures of knowledge transfer. In contrast, forward citations are those linked to a focal patent by patents filed afterward that list the focal patent as a backward citation. Forward citations indicate the existence of downstream research efforts, suggesting that money is being invested in the development of the technology. Also, the fact that a given patent has been cited by subsequent patent applications suggests that it has been used by patent examiners to limit the scope of protection claimed by a subsequent patentee, to the benefit of society. In this sense, forward citations indicate both the private and the social value of inventions. Forward citations are commonly used to measure the technological impact of innovation (Aristodemou and Tietze, 2018).

Technology Relevance is based on forward citations. Technology Relevance measures whether a patent has been more often cited than other patents from the same technology field and year, while also considering that international patent offices follow different citation rules. The total number of patent citations received not only depends on the technology field of the patented invention, but also on the time that has passed since the patent was published. Patents only recently published tend to have received much fewer citations than older patents. The time-dependency of citations is corrected by dividing the number of citations received by a patent by the average number of citations received by all patents published in the same year.

Technology Relevance also considers that international patent offices follow different citation rules. Therefore, the number of patent citations is corrected for age, patent office citation practice, and technology field. It is a relative measure comparing

one patent to other patents. A value of 2 means that the patent is twice as relevant for subsequent developments as an average patent in the same technology field and of the same age.

Competitive Impact™

The indicator Competitive Impact measures the quality or usefulness of the patent to create a sustainable competitive advantage (Ernst and Omland, 2011). Thus, both the potential to create competitive advantage through important technologies (the impact of the patents as measured by Technology Relevance) and the potential to exploit that competitive advantage in large markets (the effectiveness of the patents to avoid imitation as measured by Market Coverage) must be considered simultaneously. High Technology Relevance combined with a large Market Coverage yields high Competitive Impact and advantage for the owner. A technology, however, is worth much less without a large market to exploit it. Likewise, broad international patent protection for weak technologies are of lower value too. The level of a patent's Competitive Impact should therefore be determined based on the combination of Technology Relevance and Market Coverage. Competitive Impact is defined as the product of a patent's technology relevance and its market coverage.

Patent Asset Index™

The Patent Asset Index is an objective measure of technological strength and innovation. It considers the entire patent portfolio and takes into account both the number of patent-protected inventions and their quality or value. The Patent Asset Index is defined as the aggregated competitive impact of all patents in a portfolio.

Patent family

A simple patent family is a collection of patent documents that are considered to cover a single invention. The technical content covered by the applications is considered to be identical. Members of a patent family will have all priorities[13] in common. Patent families are assigned in an automated and manually curated process by the European Patent Office for all global patents daily.

[13] In patent, industrial design rights, and trademark laws, a priority right or right of priority is a time-limited right, triggered by the first filing of an application for a patent, an industrial design, or a trademark respectively. The priority right allows the claimant to file a subsequent application in another country for the same invention, design, or trademark effective as of the date of filing the first application. When filing the subsequent application, the applicant must claim the priority of the first application in order to make use of the right of priority. The right of priority belongs to the applicant or his or her successor in title.

Appendix D

Data sources

The **Organisation for Economic Co-operation and Development (OECD)** is an international economic organization founded in 1961 and representing 34 member countries.[14] The OECD collects internationally comparable data on R&D and the data are available in the Main Science and Technology Indicators database.[15] A useful history of the development of the OECD's R&D statistics is available.[16] Data are presented for the most recent five years for which data are available, though some countries may lack data for certain years. Where applicable, missing values were estimated using established statistical methods. Financial data are given in constant USD at current prices and corrected for purchasing power parity (PPP), allowing comparability over time and between countries. Full-time equivalent (FTE) counts are used for all human capital data in this report. The OECD's Main Science and Technology Indicators is a biannual publication that provides a set of indicators that reflect the level and structure of the efforts undertaken by OECD member countries and nine non-member economies in the field of science and technology. The indicators cover the resources devoted to R&D, patent families, technology balance of payments, and international trade in R&D-intensive industries.

Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 75 million documents published in over 36,000 journals, book series, and conference proceedings by some 5,000 publishers. Scopus coverage is multi-lingual and global: approximately 46% of titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa, and the Asia-Pacific region.

Scopus coverage is also inclusive across all major research fields, with 12,200 titles in the Physical Sciences, 13,800 in the Health Sciences, 6,800 in the Life Sciences, and 10,905 in the Social Sciences (the latter including some 4,000 Arts & Humanities related titles). Titles that are covered are predominantly serial publications (journals, trade journals, book series, and conference material), but considerable

numbers of conference papers are also covered from stand-alone proceedings volumes (a major dissemination mechanism, particularly in the Computer Sciences). Acknowledging that a great deal of important literature in all fields (but especially in the Social Sciences and Arts & Humanities) is published in books, Scopus has begun to increase book coverage in 2013. As of 2018, Scopus includes 1.5 million books, 400,000 of which are in the Social Sciences and 290,000 of which are in Arts & Humanities. For this report, most research performance indicators were extracted using SciVal, Elsevier's web-based analytics solution with unparalleled power and flexibility that provides comprehensive access to research performance data.

PatentSight provides unique, reliable, and relevant insights into the patent landscape for decision-makers and patent experts in the fields of benchmarking, R&D strategy, trend-scouting, M&A, licensing, and patent portfolio optimization. It provides simple measures that can help assess the breadth, strength, and commercial importance of a patent or patent family and yield insights on potential commercial importance. It also allows for geographic and company-based analysis of patent portfolios in order to help judge market penetration and readiness on a country-by-country basis.

[14] OECD; www.oecd.org

[15] MSTI 2013/1; www.oecd.org/sti/msti

[16] Godin, B. (2008). The culture of numbers: Origins and development of statistics on science, technology and innovation. (Project on the History and Sociology of S&T Statistics, Working Paper No. 40.) Canadian Science and Innovation Indicators Consortium

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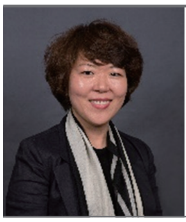

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